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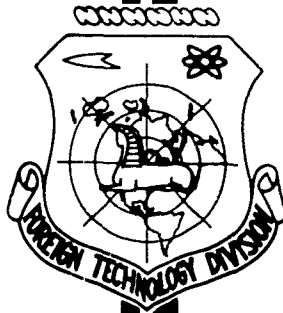
# TRANSLATION

A CAPACITANCE D-C GENERATOR OPERATING ON A NEW PRINCIPLE

By

A. A. Bal'chitis

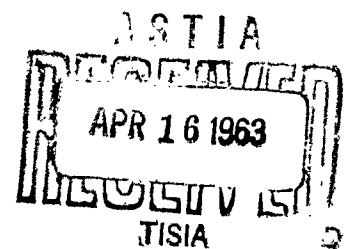
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English Pages: 18

SOURCE: Russian Periodical, Izvestiya Vysshikh Uchebnykh  
Zavedeniy Elektromekhanika, No. 10, 1959, pp. 35-43.

S/144-59-0-10-5/20

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## A CAPACITANCE D-C GENERATOR OPERATING ON A NEW PRINCIPLE

A. A. Bal'chitis

In a conductor moving across the lines of force of an electric field current is induced according to the law of current induction [1]:

$$i = \frac{dN}{dt} = D a v, \quad (1)$$

where  $D$  is the electric displacement;

$N$  is the flux of the electric displacement;

$a$  is the width of the conductor;

$v$  is the velocity;

$t$  is time.

This law affords us the opportunity to approach the solution of the problem of a capacitance machine in a new manner.

The presently known d-c capacitance machines operate in the same manner as a-c inductance machines: an alternating current is induced in the machine; it is subsequently rectified by a commutator and brushes. The presence of a commutator and brushes in the machine causes additional difficulties in design of d-c capacitance machines of large output, operating at high and super-high voltages.

In this work we examine the possibility of developing a capacitance high-voltage d-c machine, without a commutator, based on the effect of current induction in the conductor circuit by displacement of the electric field relative to this circuit.

Our examination is based on the fundamental principle arising directly from the Lagrangian equations and lying at the base of the effect of all capacitance machines. This principle states: The conversion of electrical energy into mechanical, or conversely, mechanical into electrical energy is possible in a capacitance system only by changing the capacitance of this system.

#### A Capacitance D-C Generator Operating on a New Principle

We will examine the simplest capacitance system (Fig. 1) designed to convert mechanical energy of rotary motion into d-c electrical energy. The capacitance system of such a simple machine, resembling a cylindrical capacitor, consists of two direct capacitances  $C_1$  (the system: the left electrode of the stator - the electrode of the rotor) and  $C_2$  (the right electrode of the stator - the electrode of the rotor). It is necessary to indicate here that the shape of the electrodes of the machine does not play a principal role and they can also have in another shape, for example, disk-shaped.

In order to generate an electric excitation field of the machine, the electrode of the rotor is connected to one of the poles of all independent constant-voltage source. The second pole of this source is connected to the electrodes of the stator. The load - resistance  $r$  - is connected in series to the electrodes of the stator.

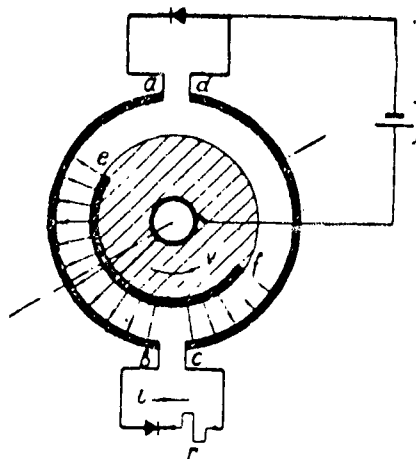


Fig. 1. Diagram of the operation of the simplest d-c capacitance machine.

In the stator circuit, rectifiers are provided which are connected in series with the load and the electrodes of the stator to direct the current of the elementary charges of the stator circuit - the induced electric current - in a given direction.

When the rotor of the machine rotates the direct capacitances of the system change periodically, but their sum remains constant and equal to the capacitance of the system:

$$C_1 + C_2 = C = \text{const.}$$

At a certain instant of time the charge held by the direct capacitances equals

$$q_1 = C_1 U,$$

$$q_2 = C_2 U,$$

where  $U = \text{const}$  is the excitation voltage.

In an operating machine the electric field moving with velocity  $v$  is displaced in time  $dt$  through a distance  $dx$  and the direct

capacitance  $C_1$  is reduced by

$$dC_1 = \epsilon_0 \frac{a dx}{\Delta},$$

and the capacitance  $C_2$  is increased by

$$dC_2 = \epsilon_0 \frac{a dx}{\Delta},$$

where  $a$  is the width of the electrode in the direction of the cylinder generatrix;

$\Delta$  is the effective gap between the stator and rotor.

Correspondingly, the charge of the direct capacitance  $C_1$  is reduced by the magnitude

$$dq_1 = U dC_1 = U \epsilon_0 \frac{a dx}{\Delta}, \quad (2)$$

and the charge of the direct capacitance  $C_2$  is increased by

$$dq_2 = U dC_2 = U \epsilon_0 \frac{a dx}{\Delta}. \quad (3)$$

Consequently in the course of  $dt$  a negative charge is transferred from the direct capacitance  $C_1$  to capacitance  $C_2$

$$dq = U \epsilon_0 \frac{a dx}{\Delta},$$

i.e., from the left electrode of the stator to the right one a current is induced whose magnitude is determined according to the law of current induction

$$i = \frac{\epsilon_0 U}{\Delta} a \frac{dx}{dt} = D a v. \quad (4)$$

The electric current induced in the main circuit of the machine can flow only through resistance  $r$  - the generator load, since the opposite direction is closed by the rectifier.

We examined only one half of the operating cycle of the machine during the course of which mechanical energy was converted into



electrical energy (resistance heating by the electric current). The second half of the cycle consists of recycling: the charges from the right electrode of the stator are returned to the left through the upper rectifier. It is evident that in this case the machine does not do useful work.

The elementary generator examined induces pulsating current in the outer circuit. In order to obtain direct current this generator must have not less than two elementary circuits generating pulsating current. These elementary circuits can be connected to the load in series or in parallel.

By direction of the current we mean the movement of a positive charge or a direction opposed to the movement of the negative charge, therefore the current induced in the main circuit of the capacitance generator under consideration is directed opposite to the movement of the electric field of the machine.

According to the principle of the continuity of an electric current, the current lines should be closed. In our capacitance machine, as a result of the induction of current in the main circuit of the machine, only local currents arise and the current lines cannot be closed in this circuit. How is the principle of continuity of current observed in this case?

When, as a result of the movement of the rotor, negative charges move from the left electrode of the stator to the right electrode, a displacement current is generated simultaneously in the dielectric between the electrodes of the stator and rotor. The magnitude of this current through the surface  $ds = adx$  (shown on Fig. 2 by a dashed line) equals

$$i_{cm} = \int_s \dot{\delta}_{em} ds,$$

where  $\vec{\delta}_{cm} = \frac{d\vec{D}}{dt}$  is the vector of displacement current density.

Taking into consideration that the flux of the vector of the electric displacement through surface  $\vec{s}$  equals the free charge in the space bounded by this surface, i.e.,

$$\oint \vec{D} d\vec{s} = q, \quad (5)$$

(Gauss' theorem), we derive

$$i_{cm} = \oint \vec{\delta}_{cm} d\vec{s} = \oint \frac{d\vec{D}}{dt} d\vec{s} = \frac{d}{dt} \oint \vec{D} d\vec{s} = \frac{dq}{dt},$$

i.e.,

$$i_{cm} = i.$$

Analogously we can show that from the side of the left electrode the displacement current has an opposite direction, i.e., here the flux of the vector of the electric displacement in section  $dx$  is changed from  $\vec{D}$  to zero.

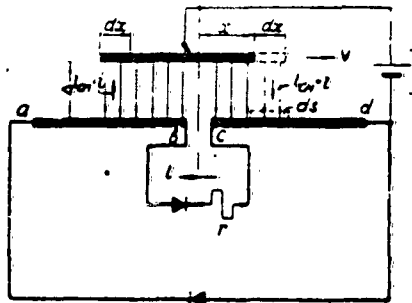


Fig. 2. Diagram of the capacitance d-c generator without a commutator.

Consequently, current  $i$  flowing through resistance  $r$  is closed not through the main circuit of the machine but through the dielectric - the principle of continuity of an electric current is not violated.

## Energy Conversion

Adhering closely to the discussion of Helmholtz, we will examine what energy conversions occur during operation of a capacitance d-c generator.

If, the resistance of the main circuit of the simple capacitance generator under consideration is zero (we disregard losses in the machine), the current induced in the machine will not do work (idling regime) and the terminal voltage of the generator will be zero. If the resistance of the main circuit is other than zero then during the flow of the induction current across the terminals of the generator, a potential difference or load voltage is developed

$$\varphi_1 - \varphi_2 = ir = u_1.$$

It is evident that the potential difference  $\varphi_1 - \varphi_2$  should balance the emf of the machine, equal to the absolute value  $u_1$  but opposite in sign.

In the capacitance machine we deal with a special form of emf. The movement of the electrical charges occurs here as a result of a purely mechanical cause: the mechanical displacement of the electric field of the machine and the charges of the stator connected with it. Nevertheless, as in other similar cases we can represent the current density of the circuit of the stator electrodes by the equality

$$\vec{\delta} = \gamma \vec{E}_1,$$

where  $\gamma$  is the conductivity.

By  $\vec{E}_1$  we mean here the electric field intensity generated by the external mechanical force. This mechanical force can be expressed by the equality

$$f = E_1 q. \quad (6)$$

But charge  $q$ , according to (5), equals:

$$q = \oint \bar{D} d\bar{s} = \oint \bar{D} [d\bar{x} d\bar{a}] \quad (7)$$

and the external mechanical force displacing the charges in the stator circuit can be expressed by the equality

$$f = E_1 \oint \bar{D} d\bar{s}, \quad (8)$$

or

$$f = E_1 dx a D = u_1 a D, \quad (9)$$

where  $u_1 = E_1 dx$  is the load voltage.

It is of interest to compare the expression derived (9) with an analogous expression for the acting mechanical force during operation of an induction machine. As is known, for the induction machine

$$f = i l B.$$

A mathematic analogy of both the cited expressions once again proves the relationship of physical phenomena in electric and magnetic fields.

During the flow of the induction current in the main circuit of the machine, in addition to the main excitation field normal to the electrodes of the stator, there is a tangential component of the electric field - the field of the load which, according to the law of conservation and conversion of energy, should generate an electrical force  $f_e$  such that it could balance the external mechanical force  $f$  (we are considering a steady-state work regime of the machine) according to the equality

$$fv = f_e v, \quad (10)$$

or

$$fv = u_1 a Dv. \quad (11)$$

Turning our attention to the law of current induction (1), equality (11), expressing the power of the machine, can be rewritten in the following form

$$p = fv = u_1 i. \quad (12)$$

This equality shows that in a capacitance d-c generator mechanical power is converted into electric current power.

According to Lenz's law, the phenomena arising as the result of current induction can be described by a more general law which is a special case of the law of the conservation and conversion of energy: The current induced in a closed circuit by the displacement of the electric field produces an electric field of the load and mechanical forces such as to oppose the relative displacement of the field and circuit of the conductor.

The principle of "electric inertia" follows from this generalized law: conservation of the unchanged electric field is inherent in a capacitance system consisting of closed circuits. Attempts to change this field induce currents in the circuits and the electric field of the load is produced which tends to oppose this change.

## Structural Features, Advantages and Disadvantages of the New Capacitance Machine

The capacitance machine under consideration differs little in design from the familiar capacitance machines but the over-all dimensions and consumption of materials in the new machine are reduced considerably, mainly because of the change in the electrical circuit of the machine.

The new capacitance machine has a number of advantages as compared with d-c induction machines.

The maximum voltage of a d-c induction machine is of the order of 20-30 kv. The capacitance machine under consideration can be built for a voltage of the order of several million volts and higher and can be used in the transmission of direct current of super-high voltage (in generator-transmission line units), in x-ray technology, in ion accelerators, etc.

The speed of rotation of the d-c induction machine is relatively limited by the low mechanical strength of the armature winding. The rotor of the capacitance machine consists of two disklike metallic electrodes, the mechanical strength of such a rotor in comparison with the armature of the d-c machine is incomparably higher and it is probable that the capacitance machine under consideration can be connected with high-speed primary movers, for example, with a high-speed gas turbine without intermediate reduction gearing.

It is especially necessary to note the reduction in the consumption of materials per power unit in the capacitance machine in comparison with the induction machine.

This, in contrast to the induction machine in which it is necessary to develop bulky magnetic circuits, in the capacitance machine

we deal with direct lines of force of the electric field and complicated circuits are not required for conducting the flux of the electric displacement. Therefore in the capacitance machine the consumption of metal is smaller, in comparison with the induction machine.

We should note still another characteristic feature of the capacitance machine.

In the induction machine insulation plays a secondary role, not taking an active part in the operating process of the machine since the working field (magnetic) is concentrated in the magnetic circuit. In the capacitance machine the insulation not only separates the different electrical circuits having various potentials, but simultaneously serves as the carrier of the working (electric) field of the machine, participating directly in the operation of the machine. Therefore the utilization of insulation materials in the capacitance machine is higher than in the induction machine.

It follows from the basic relationship and the law of current induction (1) that in order to increase the power of the capacitance machine it is necessary to select a dielectric with the highest possible dielectric constant  $\epsilon$ . The remarkable achievements in the field of new insulation materials having exceptionally high dielectric constants ( $\epsilon = 1 \cdot 10^3 \dots 2 \cdot 10^3$ ) in a wide temperature range and also a distinct dependence of  $\epsilon$  on the electric field strength should favor a wider use of capacitance machines.

However, certain disadvantages are inherent in the capacitance generator under consideration as well as in all capacitance machines. A substantial disadvantage is that in order to produce high gradients of the electric excitation field the capacitance machine must operate either under a high vacuum or should be filled by a liquid or gaseous dielectric.

In order to make it possible to evaluate the relative advantages and disadvantages and to compare the sizes and weights of the machine under consideration with known electrical induction and capacitance machines, we give below an approximate calculation of the capacitance machine examined.

#### Approximate Calculation of the Capacitance D-C Generator

We will design a capacitance d-c generator having the following parameters:

Power	100,000 kv
Rpm	3,000
Rated current	50 amp
Rated voltage	2,000,000 v.

We will assume that, structurally, the capacitance generator will be made with disklike elements.

During rotation of the disk through an infinitely small angle the radius also rotates through angle  $d\varphi$  and describes the area

$$ds = \frac{1}{2} (R_1^2 - R_2^2) d\varphi,$$

where  $R_1$  is the radius of the outer circumference of the disk;

$R_2$  is the radius of the inner circumference.

The flux of the electric displacement through this area then will be equal to

$$dN = Dds = \epsilon_0 E ds,$$

and the rate of its change

$$\frac{dN}{dt} = \epsilon_0 E \frac{ds}{dt} = \epsilon_0 E \frac{1}{2} (R_1^2 - R_2^2) \frac{d\varphi}{dt}.$$



Noting that  $\frac{d\varphi}{dt}$  is the angular rotational velocity of the disk  $\omega$ , we obtain

$$\frac{dN}{dt} = \frac{1}{2} (R_1^2 - R_2^2) \omega \epsilon \epsilon_0 E.$$

Substituting this value of  $\frac{dN}{dt}$  in expression (1) we will determine the induction current

$$i = \frac{1}{2} \omega (R_1^2 - R_2^2) \epsilon \epsilon_0 E. \quad (13)$$

The outer and inner diameters of the disklike electrodes of the stator and rotor will be

$$D_1 = 135.0 \text{ cm and } D_2 = 75.0 \text{ cm.}$$

Then

$$R_1 = 67.5 \text{ cm and } R_2 = 37.5 \text{ cm.}$$

The disks are assumed to be made of duraluminum. The tensile tension in the material of the disk will be

$$\sigma_t = 2.56 \cdot 10^{-9} n^2 \frac{D_1^3 - D_2^3}{D_1 - D_2} = 2.56 \cdot 10^{-9} \cdot 3000^2 \frac{135^3 - 75^3}{135 - 75} = 690 \text{ kg/cm}^2,$$

which is permissible.

The maximum value of the electric field strength of the excitation field of the machine we will take as

$$E = 2 \cdot 10^6 \text{ v/cm.}$$

Let us assume that the machine will operate under high vacuum and the electric field strength can be taken as  $10^7$  v/cm. The safety factor here will be

$$k_s = \frac{10^7}{2 \cdot 10^6} = 5.$$

We will assign the operating gap of the machine (the distance between the electrodes of the stator and rotor) as

$$\delta = 0.7 \text{ cm,}$$

then the voltage necessary to excite the machine is,

$$u = E\delta = 2 \cdot 10^6 \cdot 0.7 = 1.4 \cdot 10^6 \text{ v.}$$

We will also assign the value of the tangential component of the electric field strength (it will depend on the form of the given external characteristic of the machine) as:

$$E_t = 0.1E = 0.1 \cdot 2 \cdot 10^6 = 0.2 \cdot 10^6 \text{ v/cm.}$$

We will assume a two-fold overload capacity (according to voltage 1). Then the total length of the serially connected elements of the stator is

$$l_{to} = \frac{2 \cdot 2 \cdot 10^6}{0.2 \cdot 10^6} = 20 \text{ cm.}$$

We obtained a very insignificant value; therefore the number of serially connected elements we will take as equal to unity, and each disk of the stator and rotor will be divided into sectors connected in parallel. Let us determine the number of such sectors connected in parallel in one disk.

The radius of the average circumference of the disk  $R_x$  can be determined from the relationship

$$R_1^2 - R_x^2 = R_x^2 - R_2^2,$$

whence

$$R_x = \sqrt{\frac{R_1^2 + R_2^2}{2}} = \sqrt{\frac{67.5^2 + 37.5^2}{2}} = 54.6 \text{ cm.}$$

The length of such an average circumference is

$$l_{av} = 2\pi R_x = 2\pi 54.6 = 343 \text{ cm.}$$

Thus the number of sectors or elements in one disk is

$$m = \frac{l_{av}}{l_{to}} = \frac{343}{20} \approx 17.$$

We will take  $m = 16$  (taking into consideration intra-element insulation).

Let us determine the current induced in one element only (two sides!). According to (13)

$$i_{t0} = \omega(R_1^2 - R_2^2) \epsilon \epsilon_0 E = 314(0.675^2 - 0.375^2) \cdot 8.855 \cdot 10^{-12} \cdot 2 \cdot 10^8 = 0.175 \text{ amp.}$$

In order that the machine produce a rated current (50 amp), it must have

$$\Sigma m = \frac{50}{0.175} = 286$$

active elements.

The same number of elements must go through the idling portion of the work cycle. Consequently, the total number of stator disks should equal

$$\frac{2\Sigma m}{m} = 2 \cdot \frac{286}{16} \approx 36.$$

The number of rotor disks is

$$36 + 1 = 37,$$

and the total number of rotor and stator disks is

$$M = 36 + 37 = 73.$$

Taking the thickness of the disks  $h$  as 1 cm, the moving weight is,

$$Q = shM \gamma 10^{-3} = 10,000 \cdot 1 \cdot 73 \cdot 2.75 \cdot 10^{-3} = 2007.5 \text{ kg,}$$

where  $s \approx 10,000 \text{ cm}^2$  is the effective area of one disk.

The moving weight per power unit of the machine is

$$\frac{Q}{P} = \frac{2007.5}{100,000} = 0.0201 \text{ kg/kw,}$$

as opposed to 0.155 kg-f/kw for the capacitance synchronous a-c machine of the same parameters, according to A. Ye. Kaplyanskiy [2], and to 1.47 kg-f/kw for the modern 100,000 kw turbogenerator. These figures graphically show the advantage of the new capacitance machine over the other electric machines.

The losses in the capacitance machine under consideration will be negligible. In a high vacuum machine ventilation losses will be negligible but the losses to the evacuation unit will be increased.

The heat losses will be in the electric circuit of the machine. But since the current density here is very insignificant (the electrodes are selected for their mechanical strength) these losses will also be small. As a result the efficiency of this machine should be very high.

### CONCLUSIONS

A capacitance machine operating on a new principle, based on the induction of a current in a conductor moving in an electric field according to the law of current induction, permits the development of new type machine and in particular a d-c machine.

A feature of this machine, different from those capacitance machines known to us, is the simplicity of construction, since there is no commutator in this machine.

This article is limited to the consideration of a d-c capacitance generator with independent excitation from an external source. However, by filling the operating gap of the machine (or part of it) with an electret the machine should acquire the ability to become self-excited and, analogously to induction machines, can be built for a circuit of parallel, series, or mixed excitation.

What little we already do know about a capacitance generator of the new type permits us to assert the machine of this type will be widely used particularly where high and super-high voltages are needed, and also where a high-speed electric generator is required for

connection with the primary mover without reducing gears.

Submitted

June 30, 1959

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